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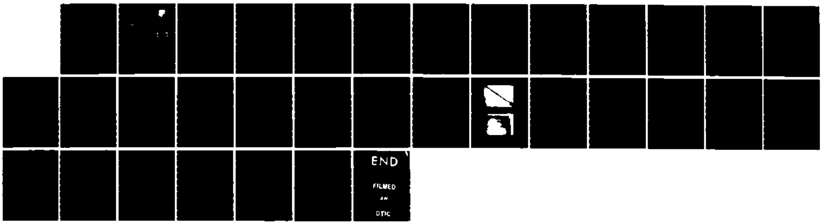

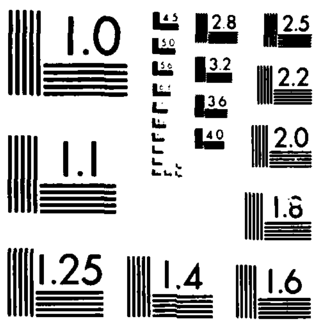
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RADC-TR-85-211
Final Technical Report
November 1985

MONOLITHIC CATHODES

Oregon Graduate Center

Paul R. Davis
Lynwood W. Swanson

AD-A163 282

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
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The purpose of this program was to evaluate LaB_6 (210) and (310) oriented single crystal material for flat cathode applications and to deliver mounted LaB_6 cathodes with (310) orientation for operation in RADC/Varian life test vehicles. To that end, the program was divided into four separate tasks, as shown in the report. This project was extended for 3 months past the initial program period, at no additional cost, so that unavoidable delays could be overcome and the project completed. The final report covers the entire period of the program, which terminated 29 March 1985.

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FINAL TECHNICAL REPORT

I. Introduction

The purpose of this program was to evaluate LaB_6(210) and (310) oriented single crystal material for flat cathode applications and to deliver mounted LaB_6 cathodes with (310) orientation for operation in RADC/Varian life test vehicles. To that end, the program was divided into four separate tasks, as shown in Table I.

This project was extended for 3 months past the initial program period, at no additional cost, so that unavoidable delays could be overcome and the project completed. This final report covers the entire period of the program, which terminated 29 March 1985.

TABLE I

PROGRAM TASK SUMMARY

Task I: Investigate clean LaB_6(210) and LaB_6(310) surface work functions, thermal stabilities and other physical properties

Task II: Investigate LaB_6(210) and LaB_6(310) interactions with tube gases at operating temperature

Task III: Investigate clean CeB_6(210) or CeB_6(310) surface work function and thermal stability

Task IV: Prepare, mount and deliver to RADC LaB_6(210) or LaB_6(310) cathodes suitable for operation in Varian life test vehicles

Pages 22 and 24 do not contain proprietary information. The information on these pages is in the public domain.
Per Ms. Joyce Watkins, RADC/TSR

II. Task I: LaB_6 Clean Surface Studies

A. Experimental Techniques

Both emission properties and vaporization rates (thermal stability) of the LaB_6(210) and (310) surfaces have been investigated in ultra-high vacuum. An improved thermionic diode system was set up to allow current density stability to be studied over long periods of time in the pulsed mode. To study the cathode emission stability in the high power DC mode (~ 580 watts at 80 A/cm^2, 1600 V, 1700 K) it is necessary to use water cooling to maintain a low collector temperature, thereby preventing the cathode from becoming contaminated with material evaporated from the collector surface. Figure 1 shows the water cooled collector which was constructed. The collector is electrically isolated from the rest of the system, by a glass tube between flanges, thus allowing the emission current to be monitored. The cathode is mounted on the two high voltage feedthroughs.

The vacuum system shown in Figure 2 was assembled to study emission characteristics in good vacuum and in partial pressures of various gases. In addition, this system was used for material evaporation (thermal stability) investigations, both in good vacuum and in partial pressures of O_2. Emission measurements made in this system have been related to thermal stability results, as discussed later in this report.

B. Experimental Results

Figure 3 shows J-F data obtained for a LaB_6(310) cathode in the pulsed mode using this system. These results are presented here as log J vs $F^{1/2}$ plots, with the Child's law (space charge limited) regime at low fields and the Schottky regime at high fields. Note that the "knee," or transition region, occurs, for example, at about 4 A/cm^2 for a cathode temperature of 1500 K.

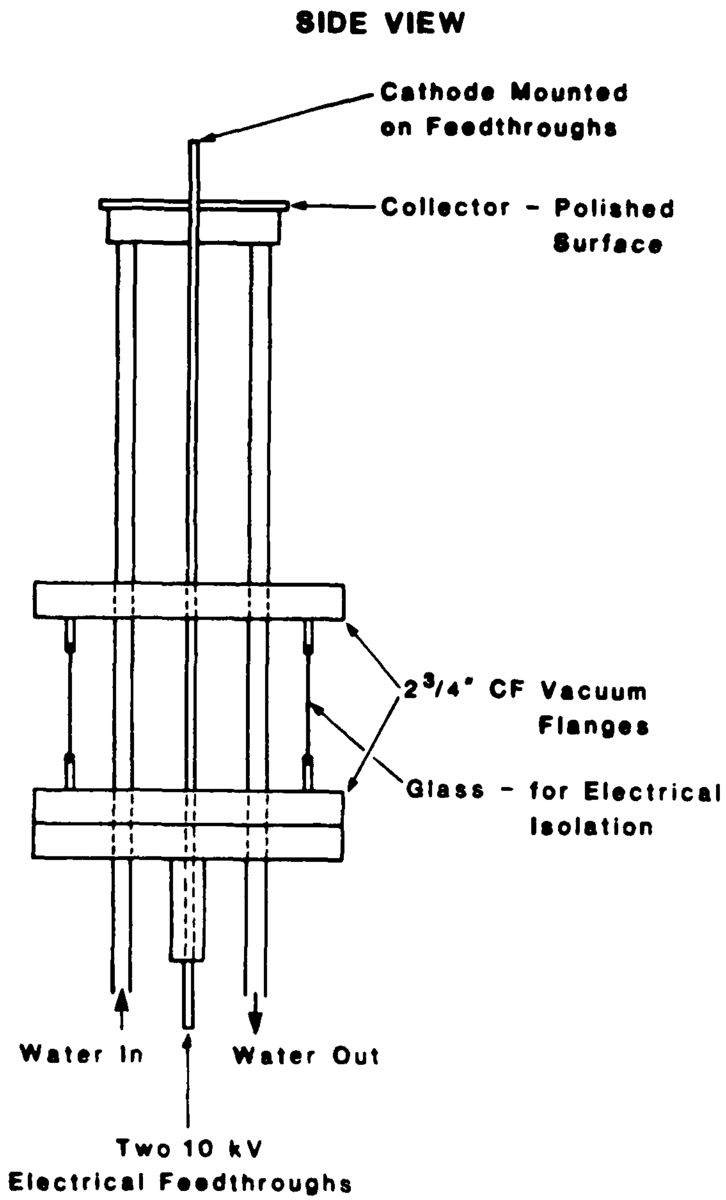


Figure 1. Water cooled collector used to study DC emission from LaB_6 and CeB_6 cathodes.

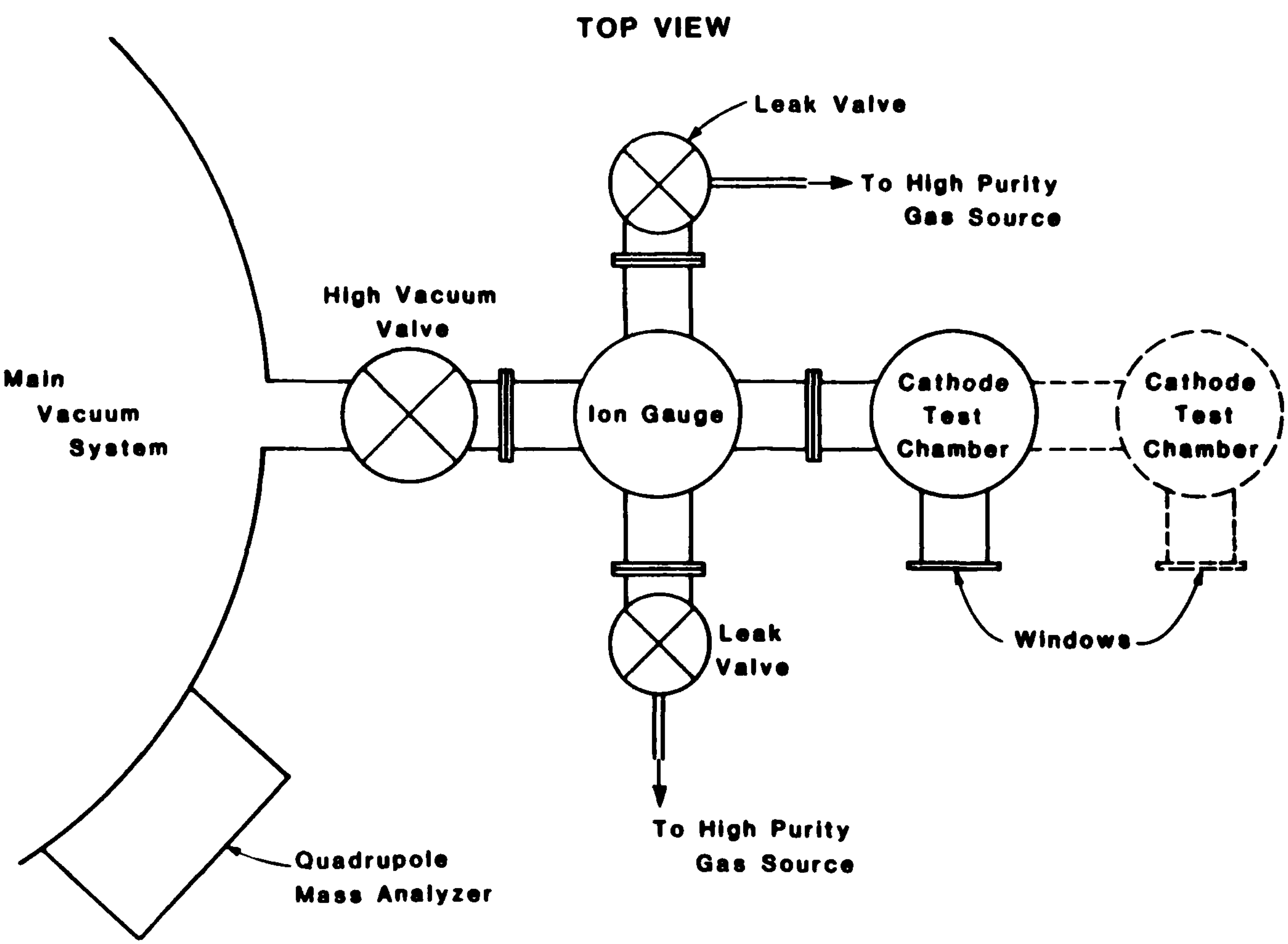


Figure 2. Vacuum system to study emission and thermal stability characteristics of LaB_6 and CeB_6 cathodes.

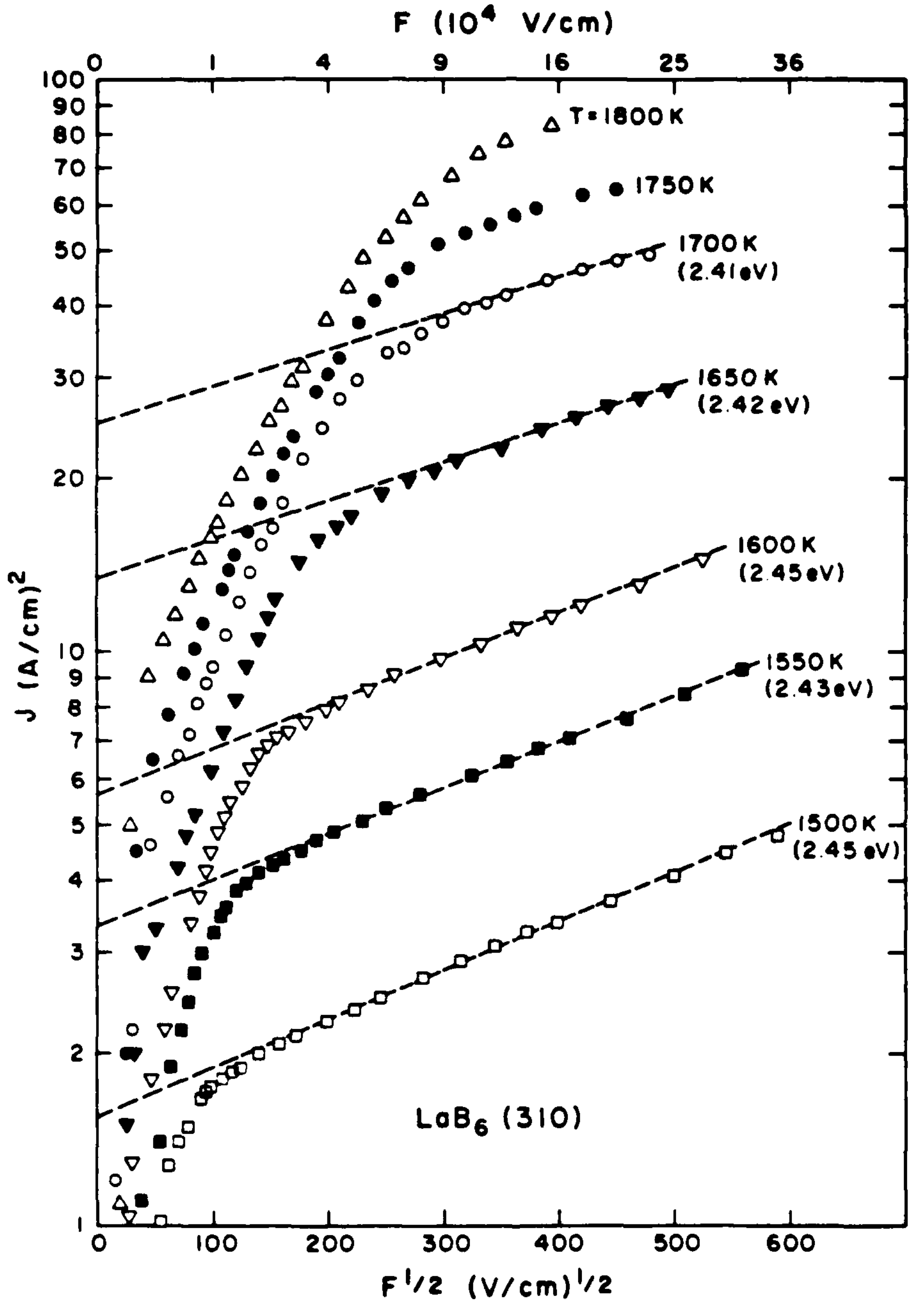


Figure 3. Emission characteristics of a $LaB_{6.09}$(310) surface, measured in a pulsed thermionic diode at various indicated temperatures. In the Schottky (high field) emission regime, the current density J is expected to be a linear function of the square root of the applied field F. At low values of F, the emission exhibits Child's Law (space-charge limited) behavior.

Figure 4 is a comparison of 1700 K data like that of Fig. 3 with the Child's law-Schottky line curve. The comparison of Fig. 4 is based on a planar diode configuration fit with a cathode work function of 2.36 eV. The observed deviation from the calculated curve is to be expected, even for an ideal cathode, in a planar diode, as has recently been pointed out by Scott,[1] since an abrupt transition from the retarding to accelerating regimes is an oversimplification of the true diode behavior. In fact, space charge effects <u>are</u> present within the accelerating field range, and these effects cause knee rounding and gradual approach to the Schottky line in J-F plots.

Figure 5 summarizes effective thermionic work function variation with temperature of the (210) and (310) surfaces under clean vacuum conditions with $P \leq 1 \times 10^{-9}$ torr. The (100) surface behavior is included for comparison. Note that both the (210) and (310) surfaces exhibit considerably lower work functions than the (100) surface. At 1600 K, $\phi_{(310)}$ is approximately 0.25 eV lower than $\phi_{(100)}$, corresponding to an increase in zero-field emitted current density by a factor of about six, from 1.4 to 8.3 A/cm^2. This dramatic result suggests that cathodes with <310> orientation should be able to emit current densities of 1 A/cm^2 at approximately 1450 K and 2 A/cm^2 at less than 1500 K. These are emission current densities used in standard life test studies.[2]

Emission capabilities comprise only half of the story for cathode characterization. The other parameter of interest is lifetime, which can be considered to be long-term stability at the operating temperature. Thermal stability for LaB_6 cathodes is equivalent to vaporization rate or material loss rate. All the LaB_6 results discussed in this report refer to single crystal samples of B/La = 6.09 stoichiometry, the best value we have found for maximizing electron emission and minimizing material loss.

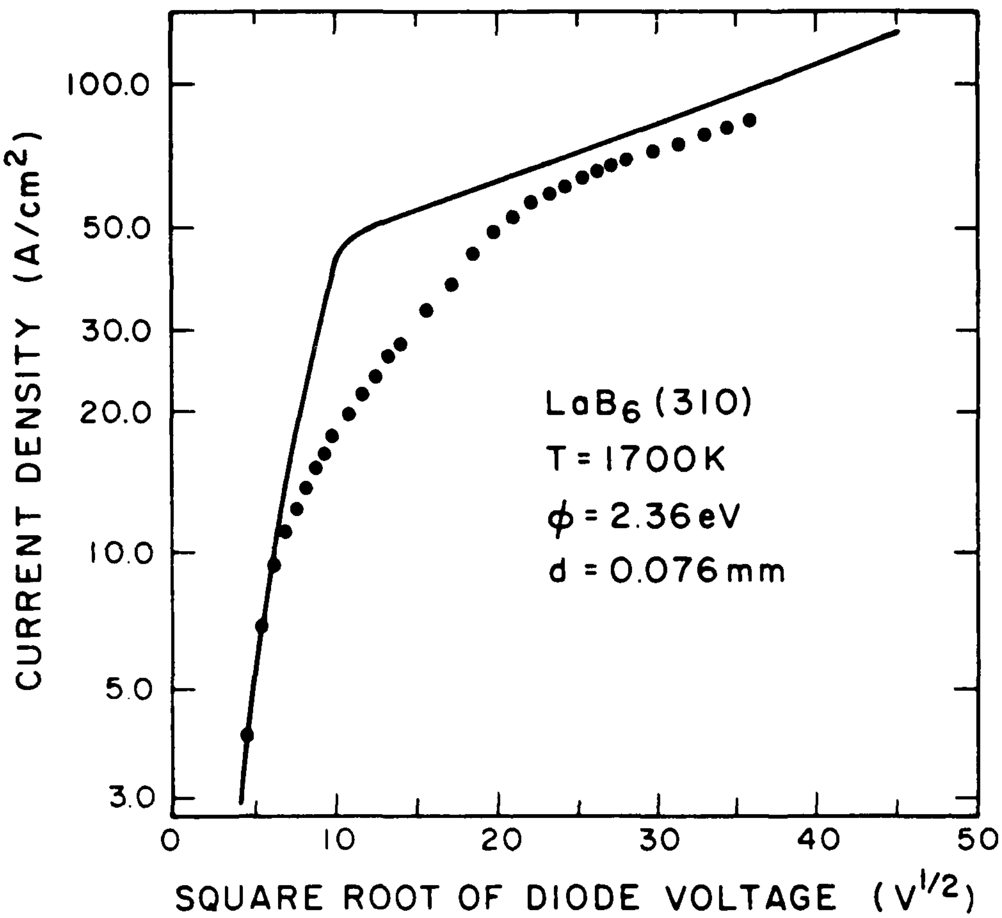


Figure 4. Comparison of LaB_6(310) J-V data (points) at 1700 K with the predicted Child's law-Schottky line (solid), in the region of the knee. Data from Figure 3. A work function of 2.36 eV was used to calculate current density in the Schottky regime.

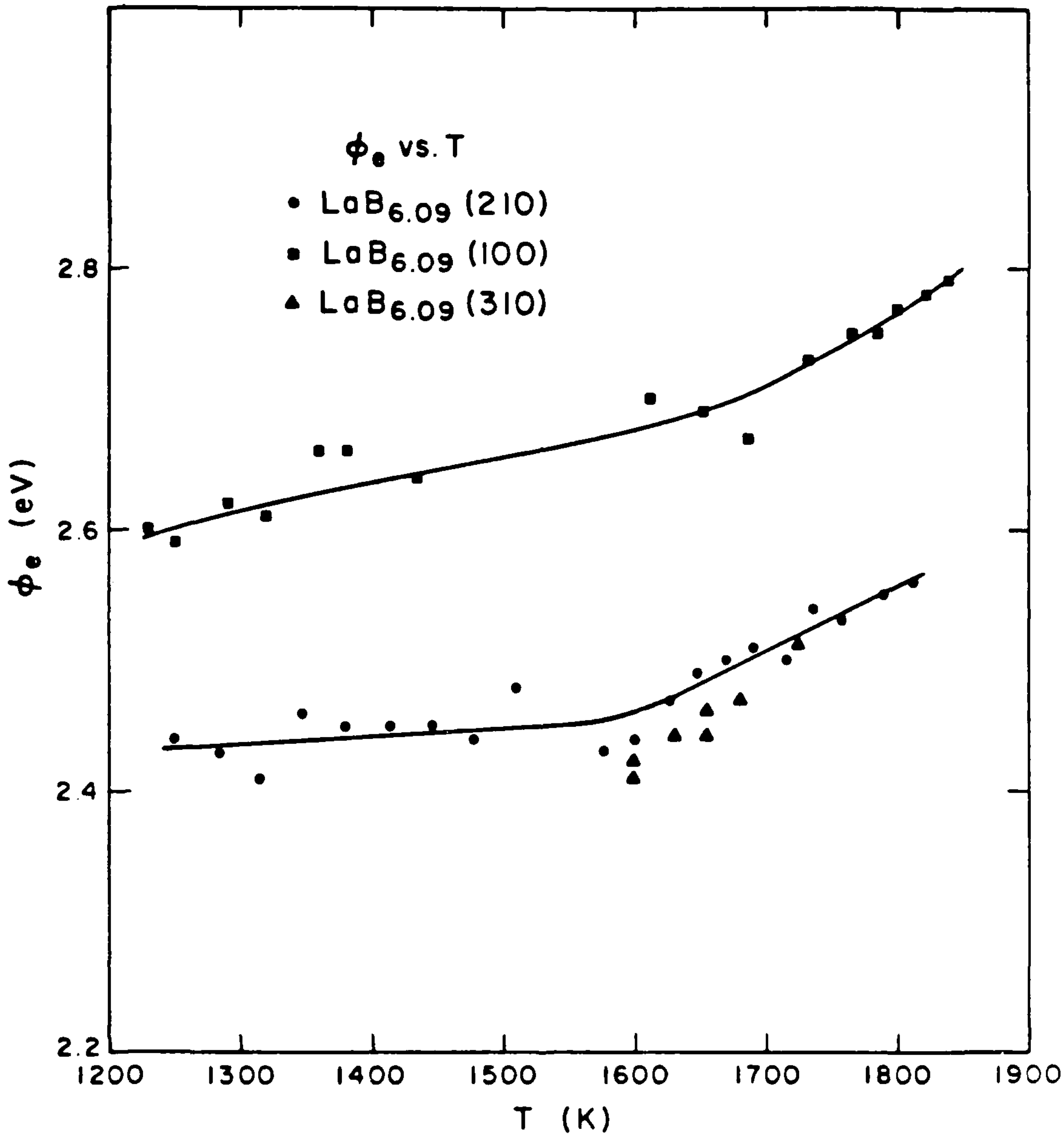


Figure 5. Temperature dependences of thermionic work functions, ϕ_e, of the (100), (210) and (310) planes of $LaB_{6.09}$.

Figure 6 shows the results of evaporation rate experiments we have performed on a variety of $LaB_{6.09}$ crystals, each point corresponding to one mounted cathode. Measurements of cathode dimensional changes were made following heating under various vacuum conditions at the indicated temperatures. Particular attention should be focused on curve (D), corresponding to ultra-high vacuum conditions. In this situation, material evaporation is isotropic, meaning the rate is the same from all crystal faces. Thus, faceting of the cathode surface does not occur under these conditions.

Data from Figures 5 and 6 can be combined into a figure of merit plot showing the ratio of emitted current density to material evaporation rate. On this basis, different types of cathodes may be compared, as in Figure 7, where LaB_6(210), LaB_6(310) and an impregnated dispenser cathode (IDC)[3] are compared. Note in Figure 7 that both (210) and (310) LaB_6 have figures of merit superior to an M-type IDC over the entire range of operating temperatures. At 1400 K the M-type IDC undergoes rapid alloying of the Os layer with the W matrix, an effect which increases the cathode work function and reduces the emitted current density.

III. Task II: LaB_6 Interactions with Tube Gases

The thermal stability studies in O_2 constitute an important part of the overall project. In order to determine the effect of O_2 on the evaporation rate, O_2 was leaked into the vacuum chamber during evaporation. The quantitative results of this investigation for O_2 are given in Fig. 6 for 1×10^{-7}, 5×10^{-7} and 1×10^{-6} torr O_2. As expected, the presence of O_2 increases the evaporation rate due to the formation of volatile oxides. Furthermore, some interesting features of the O_2 effect have been observed.

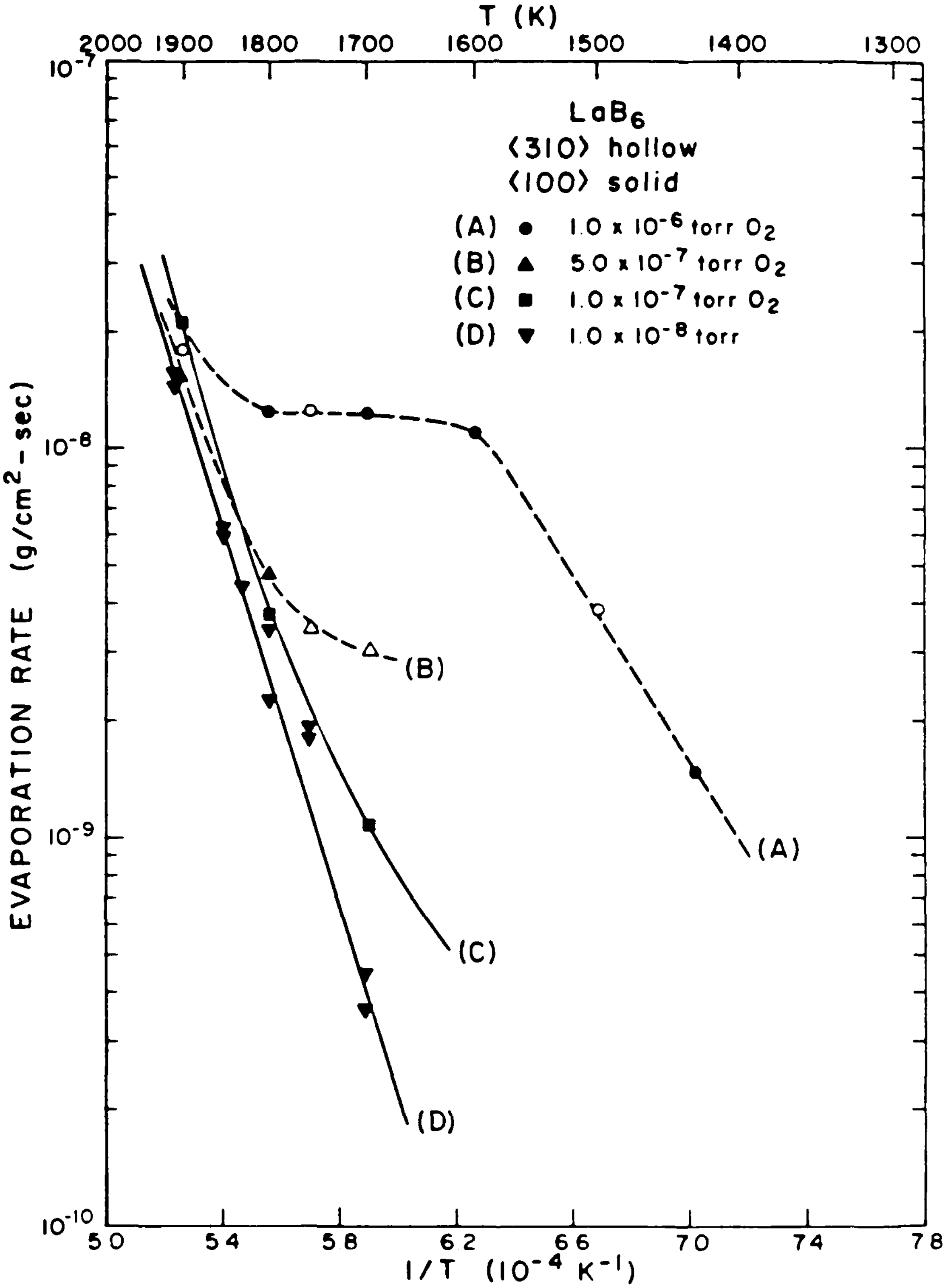


Figure 6. Results of long-term evaporation studies of $LaB_{6.09}$ single crystals in good vacuum and in various O_2 pressures, using conical conical specimens. The open points indicate <310> and the solid points indicate <100> axial specimen orientation.

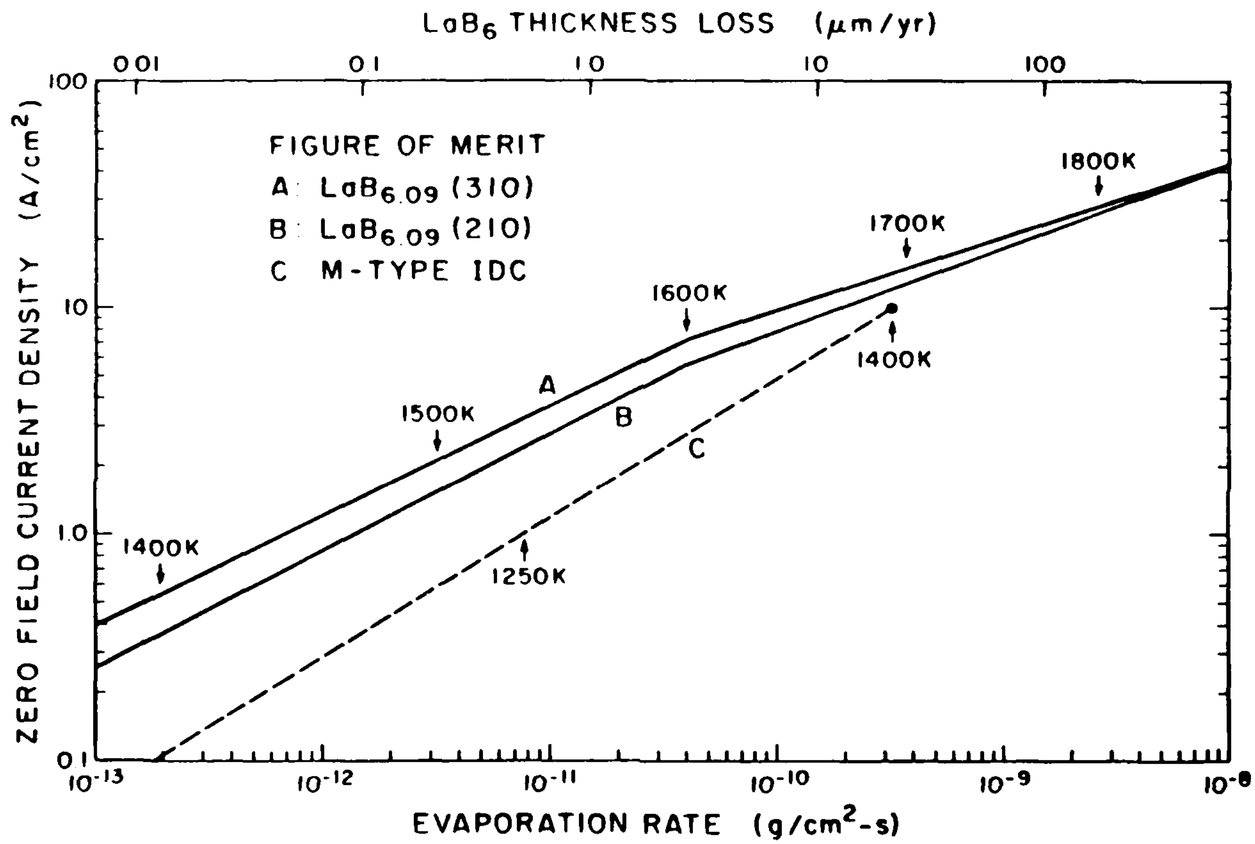


Figure 7. Figure of merit comparison of LaB_6(310) and (210) faces and a state-of-the-art M-type impregnated dispenser cathode (IDC).

As shown in Fig. 6, the effect of O_2 on the evaporation enhancement is greatest for the lower temperature range. (In an earlier study[4] it was shown that no evaporation of La or B containing products occurred at $P_{O_2} \leq 2 \times 10^{-6}$ and $T < 1000$ K.) For $T > 1850$ K there is a negligible effect of O_2 on the evaporation rate. At the highest O_2 pressure studied here (1×10^{-6} torr), the rate of evaporation becomes virtually independent of temperature for $1600 \leq T < 1850$ K. However, at 1600 K the evaporation rate increases more than 100 times when the partial pressure of O_2 is increased from $< 1 \times 10^{-8}$ to 1×10^{-6} torr. These results are indicated more clearly in Fig. 8, where the data of Fig. 6 are recast as evaporation rate vs O_2 pressure for several temperatures of interest.

Besides the increase in evaporation rate, the presence of a partial pressure of O_2 causes a significant alteration of the geometric shape of a single crystal cathode. With <100> oriented emitters, evaporation of as little as 15 μm of LaB_6 in the presence of 1×10^{-7} torr of O_2 is sufficient to initiate formation of an observable pyramidal structure. This faceting was found to be caused by a crystallographic anisotropy of enhancement of evaporation of LaB_6 in O_2. The anisotropy in evaporation rates of the major crystal planes due to this effect has been determined to be $\Delta r_{100} > \Delta r_{111} > \Delta r_{110}$.

IV. Task III: CeB_6 Clean Surface Studies

The thermal stability of CeB_6 cathodes was studied in a preliminary fashion. Figure 9 shows the results of vaporization rate measurements on two different CeB_6 cathodes in good vacuum, compared with results for LaB_6. These results suggest somewhat better thermal stability for CeB_6 than for LaB_6, especially since the stoichiometry of the LaB_6 cathodes has been optimized at

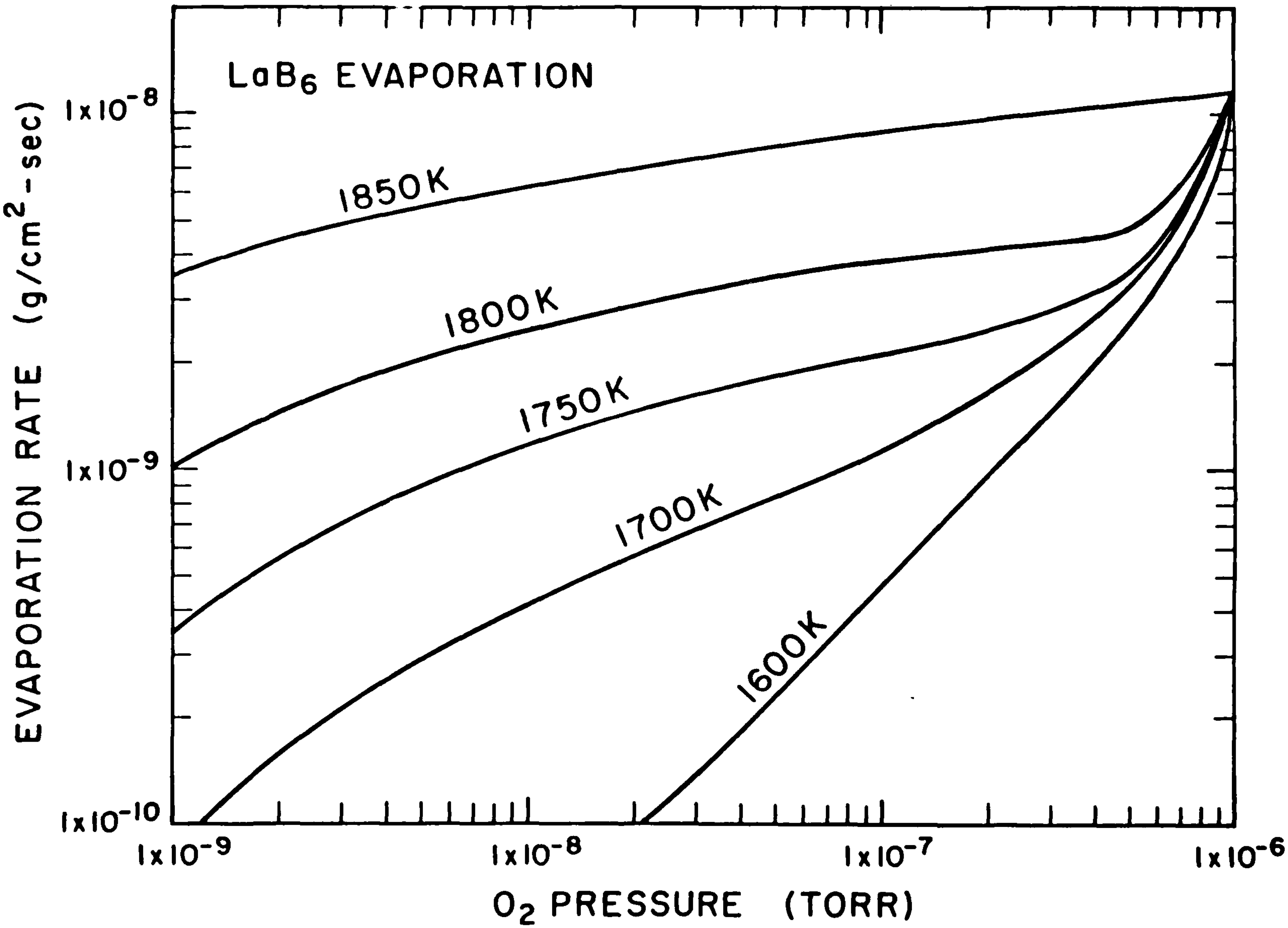


Figure 8. Variation of LaB_6 evaporation rate, at various temperatures, as a function of O_2 pressure.

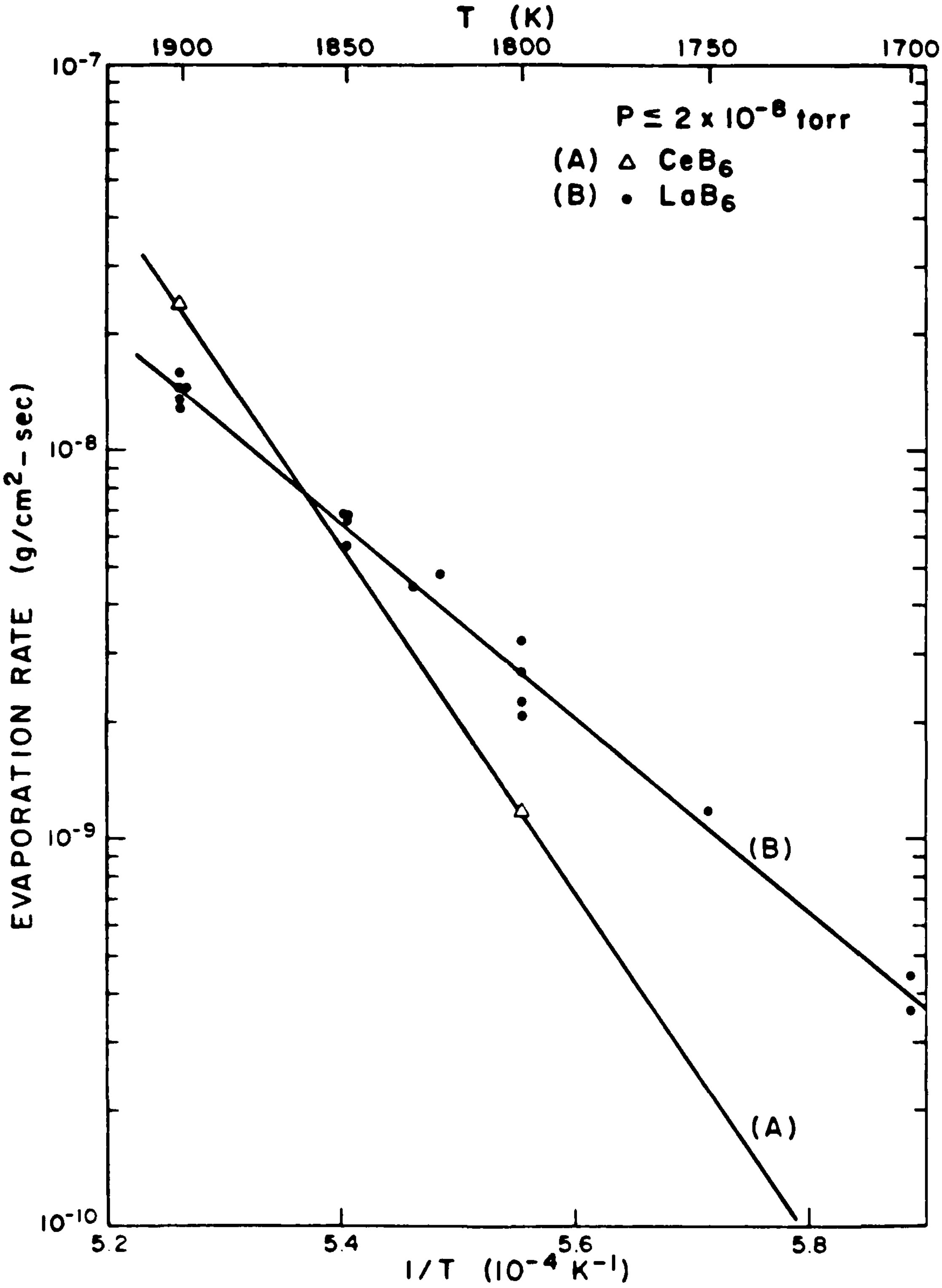


Figure 9. Vaporization rate comparison, in good vacuum, of CeB_6 (A) and LaB_6 (B). The stoichiometry of the LaB_6 cathode is op imum at B/La = 6.09, while that of the CeB_6 has not yet been optimized.

B/La = 6.09, while the least volatile CeB_6 stoichiometry has not yet been determined.

After $LaB_{6.09}$(310) was chosen as the optimum cathode surface for life test studies, investigations of CeB_6 were discontinued, although this material still holds promise and warrants a long-term research project to determine its ultimate utility as a cathode material.

V. Task IV: Prepare, Mount and Deliver LaB_6 Cathodes

A. Cathode Preparation and Mounting

The LaB_6 cathode configuration to be used in the RADC life test facility was the subject of considerable deliberation. Figure 10 shows the important details of a preliminary test configuration selected. The cathode orientation was chosen to be (310), in order to obtain maximum current density at a given temperature. Dimensions of the test cathode are indicated in Figure 10.

The test cathode was fabricated and mounted by FEI Co., Hillsboro, OR to specifications provided by the contract principal and co-investigators. Figure 11 shows the design which was chosen. Tests on the expansion of this structure at operating temperature were conducted.

A miniature prototype cathode was prepared for and delivered to NASA, Lewis Research Center, Cleveland, OH under Grant NAG3-434. This cathode was fabricated and mounted by FEI Co., Hillsboro, OR. Results of studies on this cathode are reported here because the experience gained in its operation is germane to the discussion of LaB_6 cathode development.

The miniature prototype sleeve mounted cathode structure is shown in Figure 12(a). It consisted of a .040" diameter Mo sleeve into which a .033" diameter Re cup had been spot welded. The cup held a (310) LaB_6 single crystal as can be seen in Figure 12(b). The overall length of the cathode

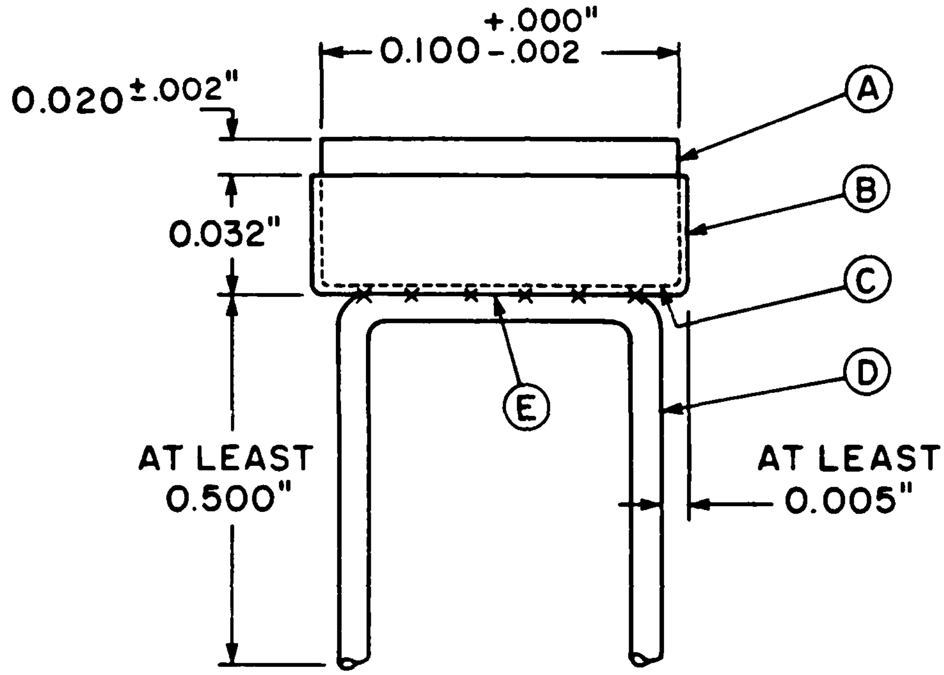


Figure 10. LaB_6(310) test cathode with integral heater. A: LaB_6(310) button; B: Re cup, 0.100 diam. × .030 deep, approx. .002 wall thickness; C: Braze; D: Re heater wire, diam. chosen so cathode can attain 1800 K minimum; E: spot welds. Dimensions in inches.

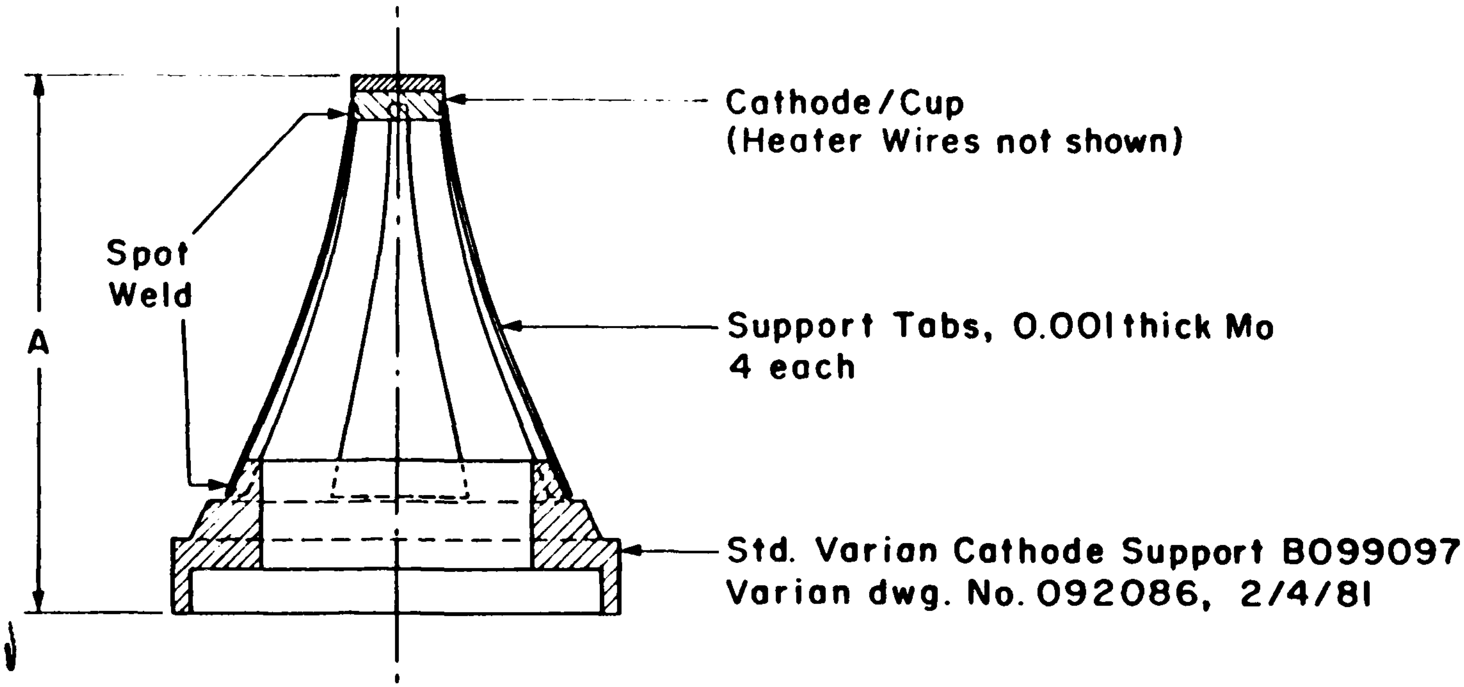
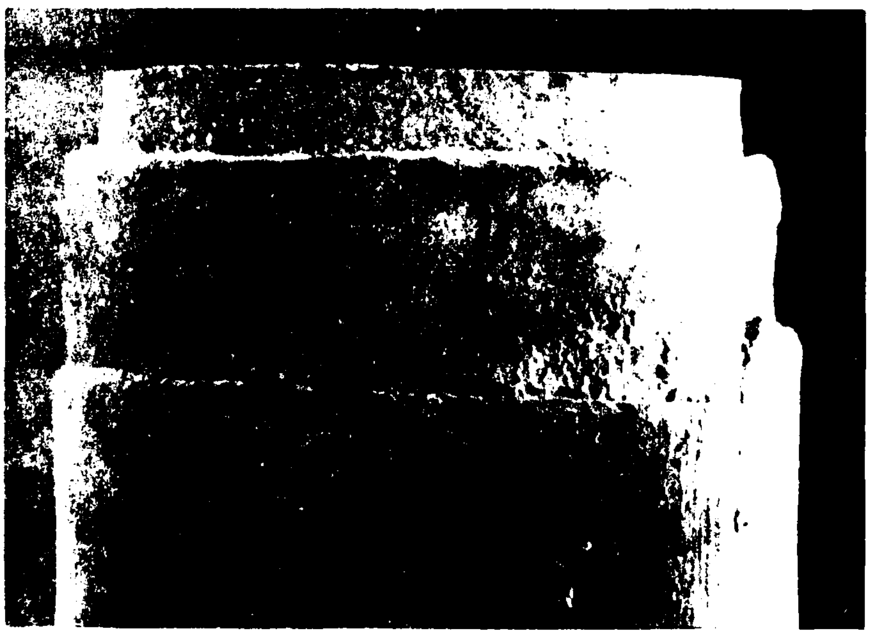


Figure 11. Detail of test cathode mounting structure.

(a)



(b)

structure was .47". Heating of the cathode was accomplished by resistively heating a .008" diameter Re wire which was spot welded to the bottom of the Re cup and held in place by a ceramic tube. The ceramic tube was press fit into a larger diameter stainless steel collar that can also be seen at the bottom of the cathode structure in Figure 12(a).

This miniature cathode structure, although very different in size from the one finally chosen for the life test vehicle allowed us to conveniently test the sleeve cathode and Re cup concepts. The heating characteristics of this structure and its structural integrity over short heating intervals at the anticipated operating temperatures were examined. Figure 13 shows the heating power and current as a function of temperature. From results discussed under Task I, we estimated that in order to achieve a current density of 5 A/cm^2 at the knee of the J(F) characteristics we would need to operate at a cathode temperature of 1500 to 1550 K. At this temperature the heating power requirement is ~ 3 W and the current required is ~ 1.7 A for the miniature prototype. For these tests the prototype cathode structure was supported by the heating leads and the temperature at the base of the sleeve was 1340 K for an emitter temperature of 1500 K.

These tests confirmed that the general sleeve and Re cup concepts used here for mounting the LaB_6 are sound. For the cathode structure used in the life test facility a .100" diameter LaB_6 crystal has been employed. Thus, the heating power requirements are correspondingly larger than for the miniature prototype. Nevertheless, on the basis of the tests on the smaller prototype structure and larger test cathode we believe that the basic sleeve concept utilizing the Re cup mount will be successful.

We have determined, as a result of our cathode mounting experiments and through discussions with personnel of RADC and Varian, Inc., that the most

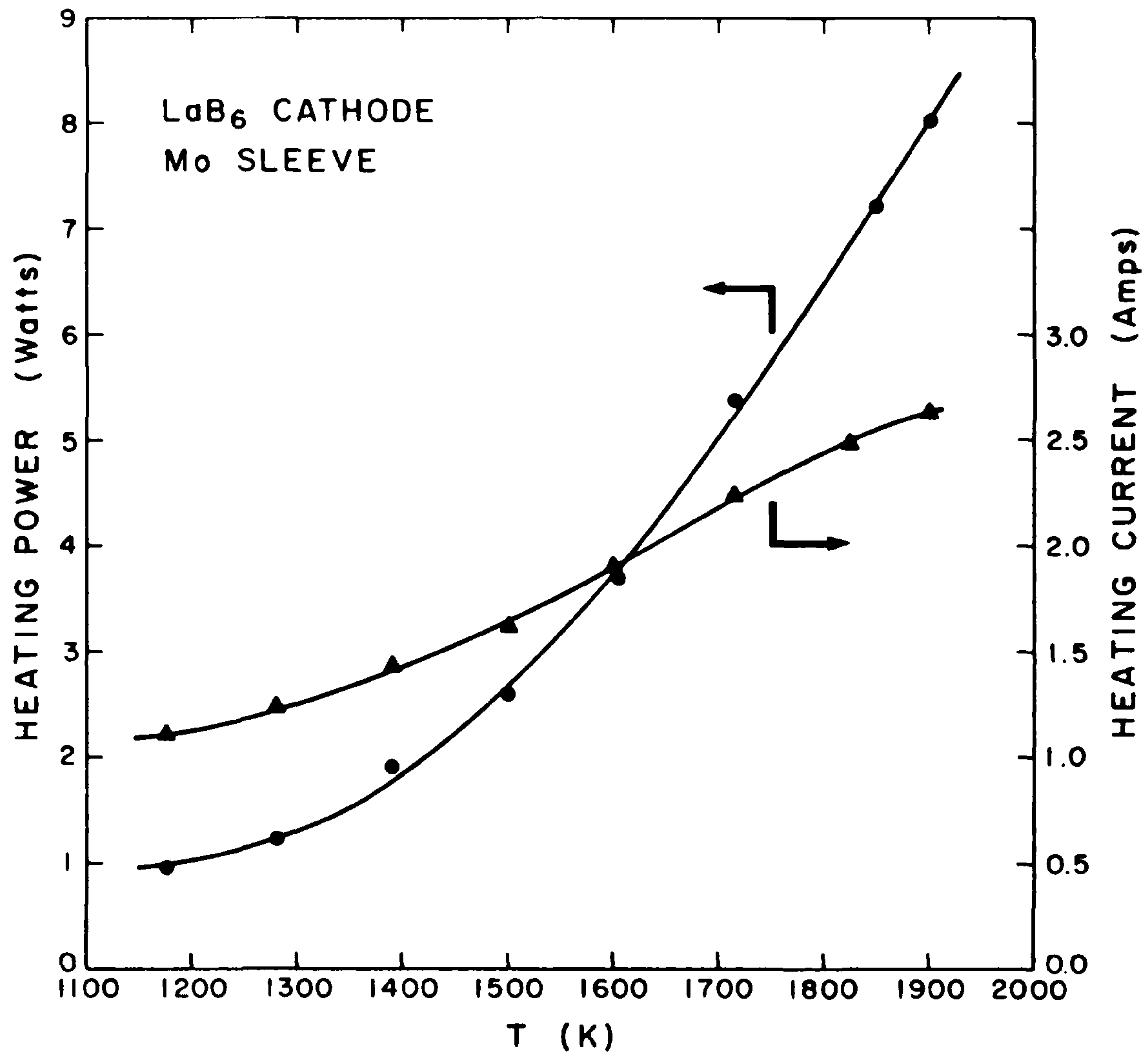


Figure 13. Heating characteristics of prototype sleeve mounted LaB_6 cathode structure of Figure 12.

stable, most practical and least expensive mounting structure for LaB_6 cathodes in RADC/Varian life test vehicles is a modified version of the standard Varian cathode assembly.

Figure 14 is a modified Varian drawing showing the Mo button which holds the LaB_6 (310) cathode. This cathode was brazed into a Re cup, which was in turn brazed into the recess shown in the button in Fig. 14.

Figure 15 shows heating test data for the cathode assembly with LaB_6 cathode installed. For these measurements the assembly was clamped by its base in a copper holder, in order to simulate mounting in an actual test vehicle. The power requirements for heating this cathode are somewhat different when installed in the actual test vehicle, since additional heat shielding is used in that case.

Figure 16 illustrates the final assembly, which is standard in all respects, except for the LaB_6 (310) cathode (not shown). Standard Varian heaters will be used with these cathodes. The illustrated cathode assembly fits the standard RADC/Varian life test vehicle. Two of these life test vehicles were reserved at Varian for use with the LaB_6 (310) cathodes.

B. Delivery of LaB_6 Cathodes

Two $LaB_{6.09}$ (310) cathodes, mounted as illustrated in Fig. 16, were delivered to Varian, Palo Alto, CA on 13 May 1985. As of 26 July, one cathode had been installed in a test vehicle and had undergone preliminary testing. The second cathode was still being mounted in a tube. Varian personnel estimate that both vehicles will be delivered to RADC before the end of August 1985.

Figure 17 is a copy of the Varian Final Data Sheet for the first test vehicle with installed LaB_6 cathode. Figure 18 is an emission rolloff plot for this tube at 2.0, 3.5 and 5.0 kV beam voltage. Note that it is possible

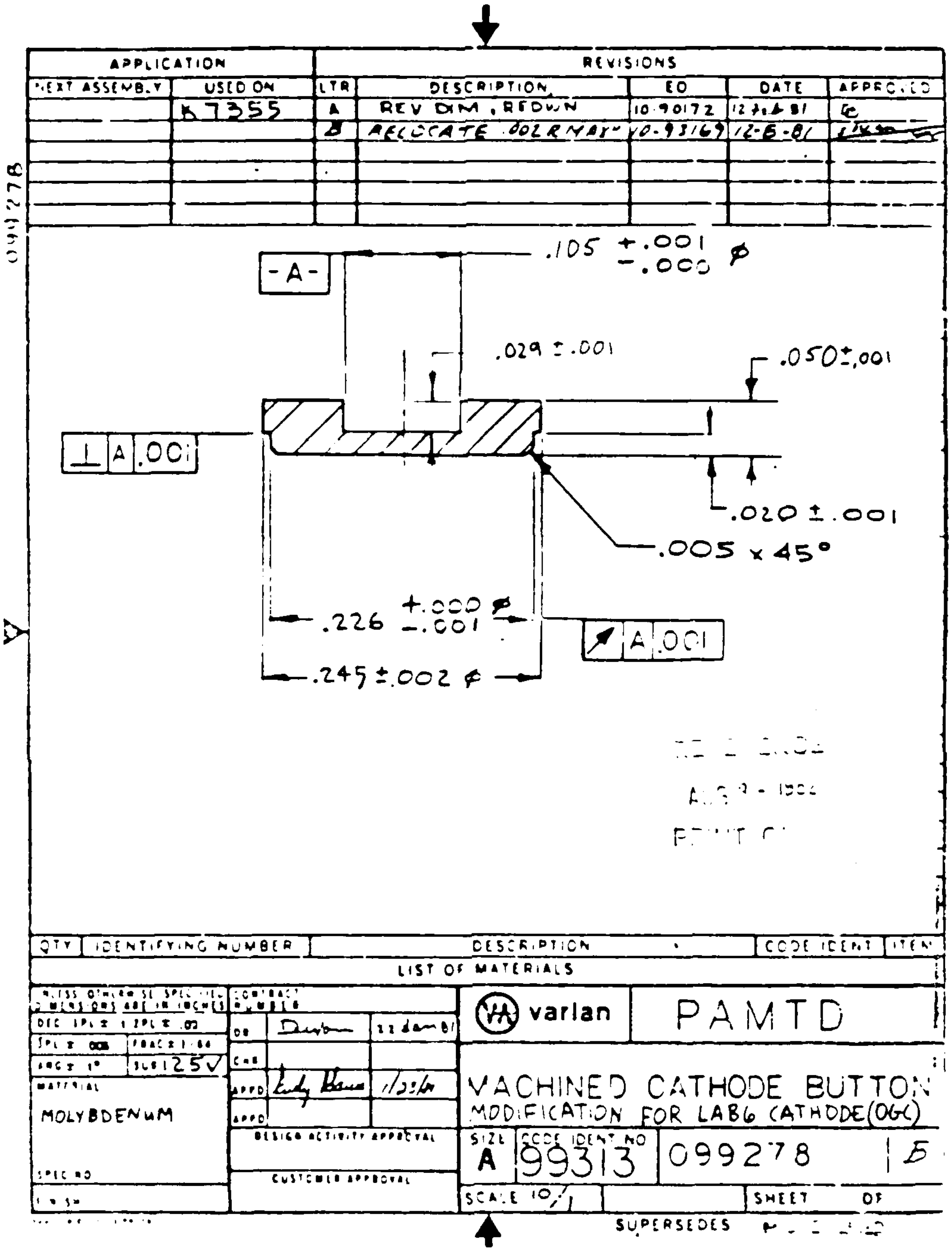
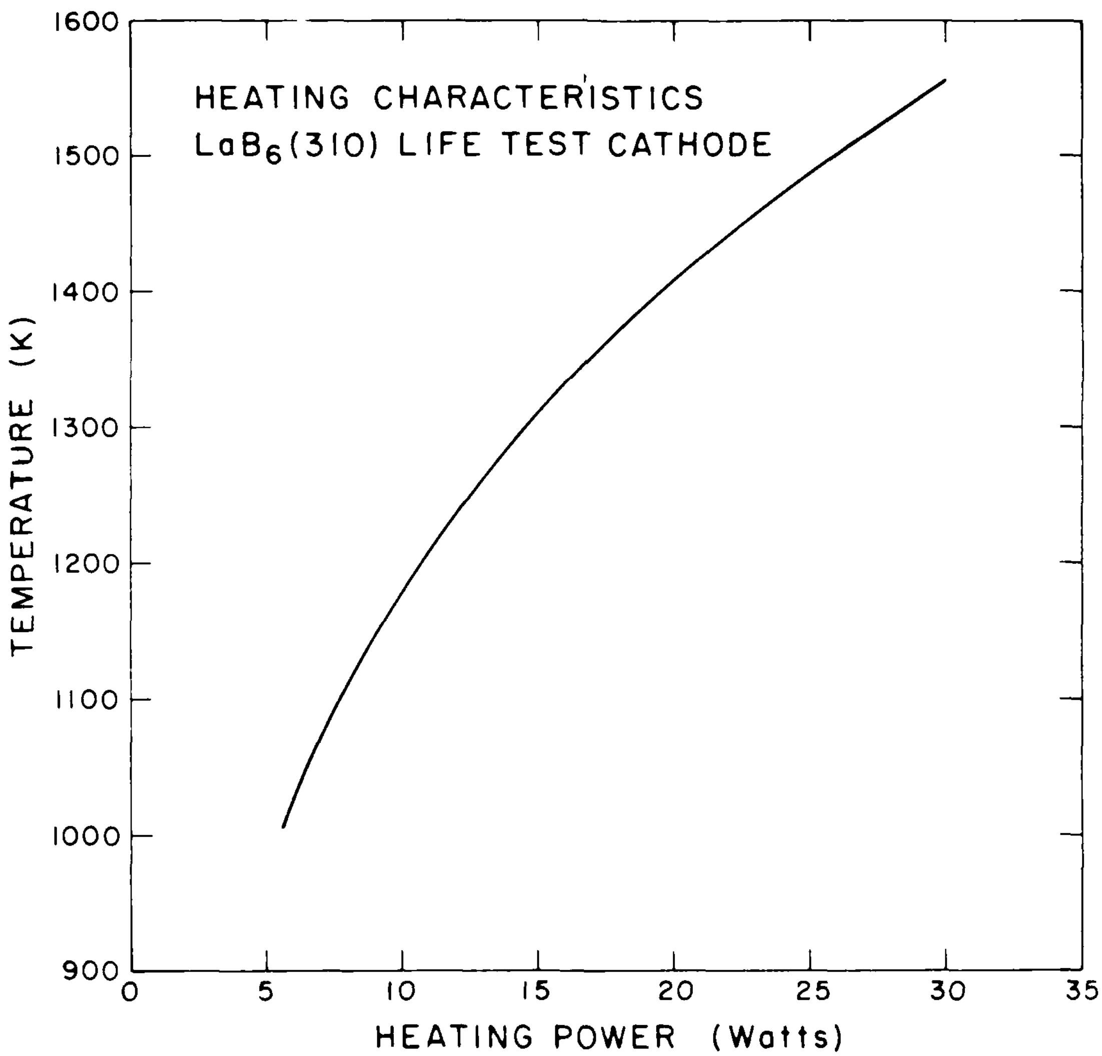


Figure 14. Modified Varian drawing of machined Mo button. A LaB_6(310) cathode in a Re cup was brazed into the recess at the top of the button.



HEATING CHARACTERISTICS
LaB_6(310) LIFE TEST CATHODE
1600
1500
1400
1300
1200
1100
1000
900
TEMPERATURE (K)
0
5
10
15
20
25
30
35
HEATING POWER (Watts)

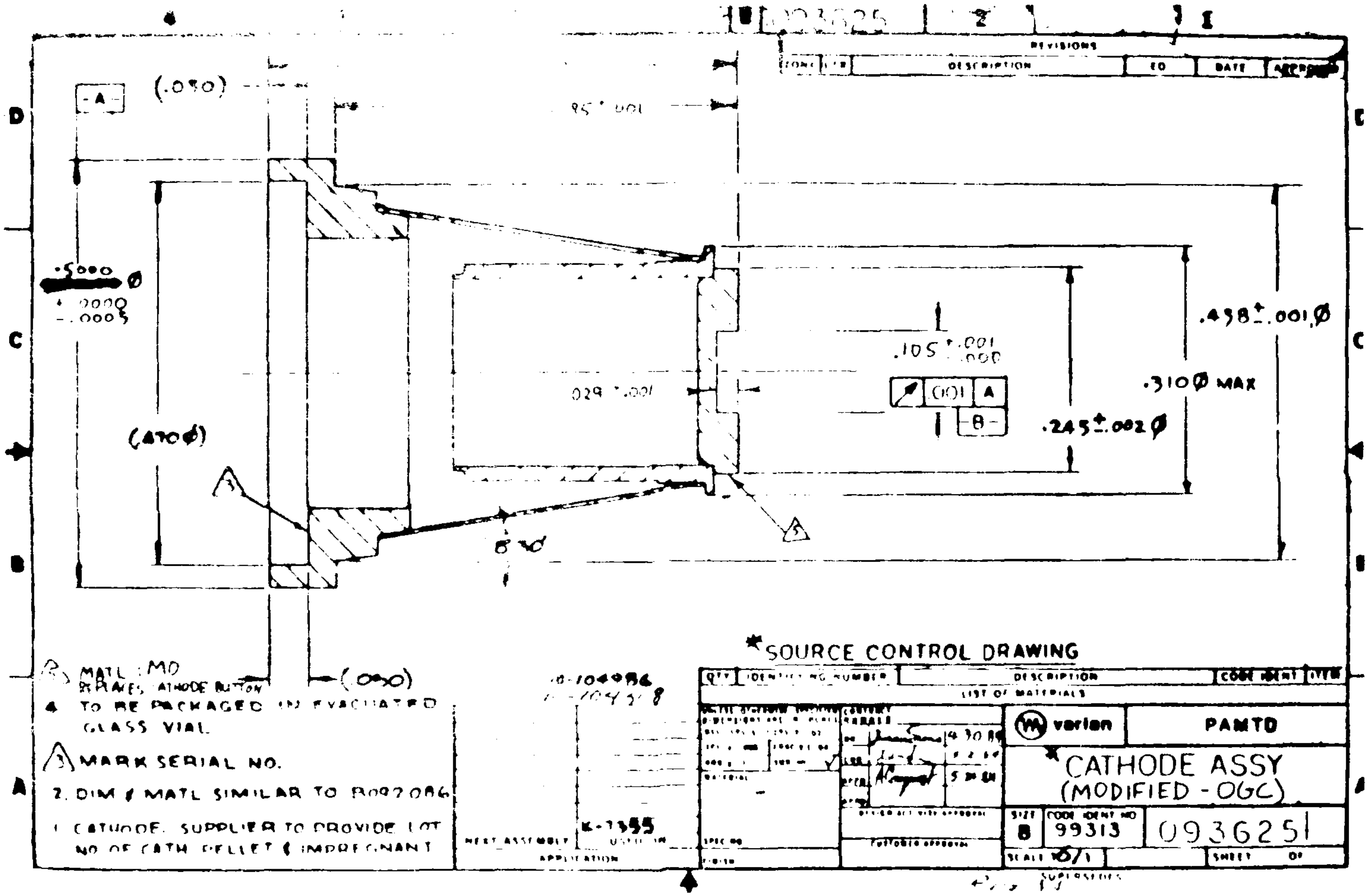


Figure 16. Modified Varian drawing of the standard cathode assembly for the RADC/Varian life test vehicle. The modification shows the button of Figure 14.

V-7355 LIFE TEST VEHICLE FINAL DATA SHEET

Test Vehicle S/N:	216
Gun S/N:	103AA
Cathode S/N:	LaB6 Blue

CONFIGURATION:

- Life Test Vehicle (V-7355) P/N B099265 Rev. ________
- Final Cathode Assembly (Gun) P/N C092095 Rev. ________
- Cathode Support Assembly (Cathode) P/N B092086 Rev. ________

ACCEPTANCE DATA:

Item	Test Parameter	Test Specification	Accept
A	Cathode Temperature	~~[illegible]~~ SPECIAL	✓
B	2 liter/sec. Pump Pressure	1×10^{-7} Torr max	✓
C	Perveance	0.5 ± 10% μ perv	.436 μP
D	Leakage Current ($E_b = E_c = 10kV$)	Collector 150 μA max Cathode 150 μA max	10 μA 0 μA
E	Total Age Time	20 Hr. min	203.7 Hr

ATTACHMENTS:

1. ~~Miram Plot~~ ROLL-OFF CURVE ✓
2. Cathode Fabrication Data Sheet ✓

Tested By: RS / EA Conquest Date: 7-24-85

QA Approval: ________ Date: ________

87-000-746 8/84

Fig. 17. Final data sheet for LaB_6(310) test vehicle S/N 216.

to achieve space-charge limited operation only at 2.0 kV within the heater limitation of about 1270°C_B with this cathode. The position of the knee in Fig. 17 (1250°C_B or 1550 K) implies a cathode work function of 2.6 eV, considerably greater than the 2.4 eV observed in carefully controlled laboratory experiments (see Section II). This higher work function value may be attributed to contamination present on the LaB_6 surface, which needs to be heated to > 1600 K for cleaning.

We expect to maintain contact with RADC personnel during the startup and test periods of these vehicles, in order to minimize possible problems.

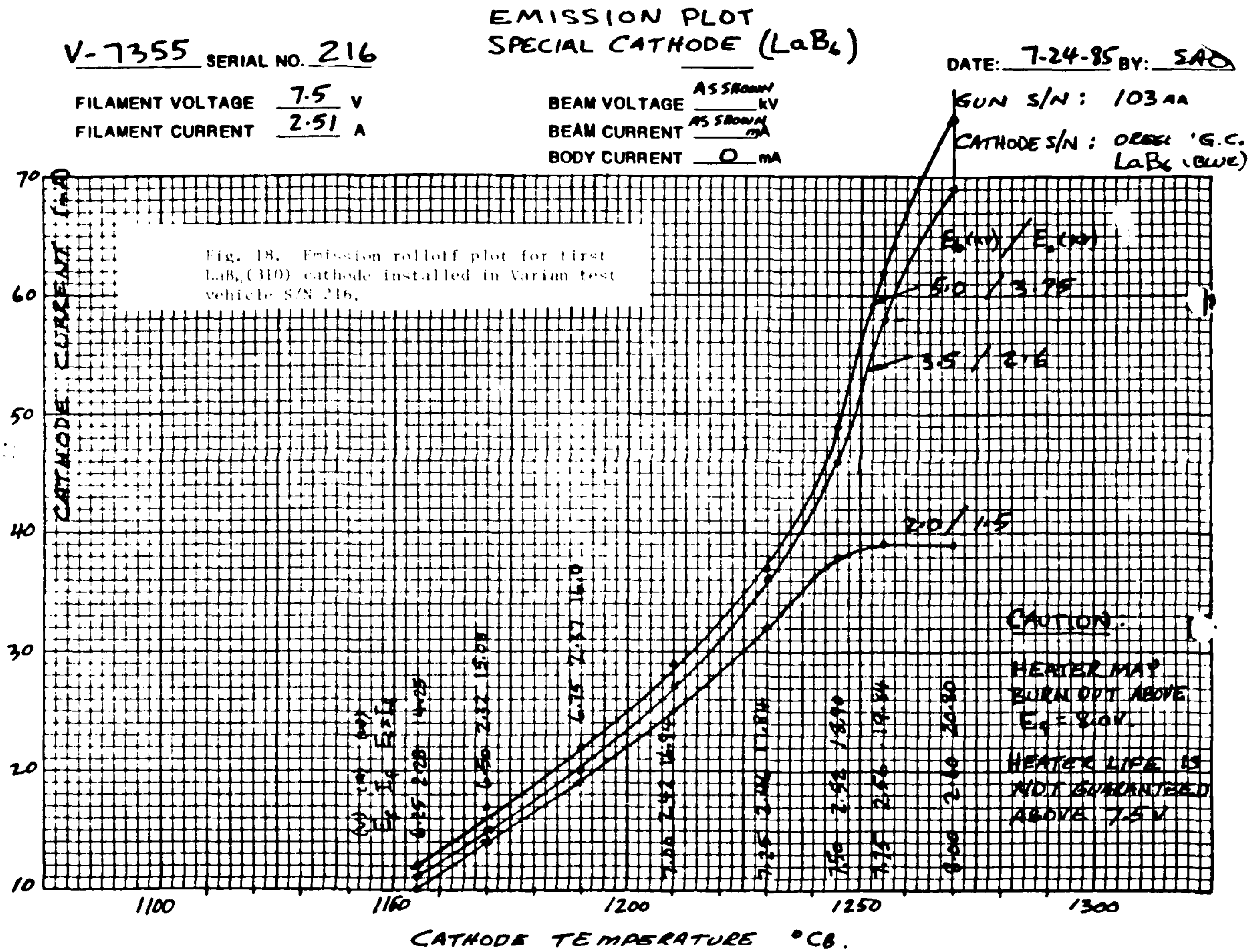


Fig. 18. Emission rolloff plot for first LaB_6(310) cathode installed in Varian test vehicle S/N 216.

REFERENCES

1. J. B. Scott, J. Appl. Phys. 52 (1981) 4406.

2. D. Bussey, RADC. (Private communication)

3. IDC vaporization data taken from R. A. Tuck, Appl. Surf. Sci. 2 (1979) 128.

4. P. R. Davis and S. A. Chambers, Appl. Surf. Sci. 8 (1981) 197.

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